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ABSTRACT

The use of technology such as computers and programmable calculators enables students to find p-values and conduct tests of hypotheses in many different ways. Comprehension and interpretation of a research problem become the focus for statistical analysis. This paper describes how to calculate chisquare statistics and p-values for statistical tests of hypothesis with spreadsheets, especially LOTUS 1-2-3 for Windows. The chi-square probability distribution is approximated by techniques including series expansions and Simpson's Rule. The construction of spreadsheet macros to perform these calculations is demonstrated. Meanings and applications of the chi-square probability distribution to a number of examples are illustrated for students with various mathematical backgrounds. A description of the use of a computer algebra system, DERIVE, for computing p-values is also provided in the appendix. The use of technology as a tool for learning and doing statistics is emphasized. An appendix discusses other ways to find p-values. (Contains 10 tables and 9 references.) (Author/SLD)

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Chi-Square Statistics, Tests of Hypothesis and Technology

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Abstract

The tables provided in the back of statistics textbooks are becoming obsolete. The use of technology such as computers and programmable calculators enables students to find pvalues and conduct tests of hypothesis in many different ways. Comprehension and interpretation of a research problem become the focus for statistical analysis. This paper describes how to calculate chi-square statistics and pvalues for statistical tests of hypothesis with spreadsheets, especially LOTUS 1-2-3 for Windows. The chi-square probability distribution is approximated by techniques including series expansions and Simpson's Rule. The construction of spreadsheet macros to perform these calculations is demonstrated. Meanings and applications of the chi-square probability distribution to a number of examples are illustrated for students with various mathematical backgrounds. A description of the use of a computer algebra system, DERIVE for computing pvalues is also provided in the appendix. The use of technology as a tool for learning and doing statistics is emphasized.

Introduction

Calculating the chi-square value for a test of hypothesis is a tedious computational process. This process interferes with learning meanings and concepts. With technology use, focus on learning shifts from computation to interpretation and analysis. Examples of how to calculate the chi-square statistic and the pvalue, and how to make decisions to reject or not to reject the null hypothesis are illustrated with the LOTUS 1-2-3 for Windows spreadsheet. Also macros are displayed for finding the pvalue using series expansions and Simpson's Rule. The chi-square statistic has many applications. For example, the goodness of fit application is used to determine whether collected data fit a specific probability distribution. Another application of the chi-square statistic is determining whether data in two or more groups are independent of each other. Examples of applications of the chi-square statistical test of hypothesis are provided.

The Chi-Square Statistic

By definition, where v is the number of degrees of freedom, z is the variable of integration and $\Gamma(v)$ is the gamma function, $F(x) = \frac{1}{\Gamma(v/2)2^{v/2}} \int_0^x z^{(v/2-1)} e^{-z/2} dz$ represents the area under the chi-square distribution from 0 to x (Hogg & Tannis, 1997). The right tail area or pvalue is found by calculating 1- F(x). The evaluation of this integral can not be found directly or in closed form. Applying series expansions (Poole & Borchers, 1979; Abramowitz, 1972) and approximation techniques such as Simpson's Rule (Larson, Hostetler, & Edwards, 1998) enable the user to find a specific pvalue. The gamma function defined as $\Gamma(n) = \int x^{n-1} e^{-x} dx$, where n>0 for n any integer, is also found by using Simpson's Rule.

Calculating the Chi-Square Statistic

When a chi-square statistic is calculated or a statistical test of hypothesis is conducted with technology such as spreadsheets, students do statistics and interact with concepts. Determining the chi-square statistic requires collecting oberved data and comparing these values to expected values. Expected values are calculated by using E = np where n is the number of values in each group and p is the probability of obtaining a value in that group. The chi-square statistic is calculated by using $\Sigma (O-E)^2/E$. (For computing expected values in contingency tables see Blaisdell, 1998). Table 1 displays the use of a spreadsheet to calculate the chi-square statistic for 10 groups.

Insert Table 1 About Here

Finding Pvalues by Series Approximations

The pvalue for the chi-square probability distribution can be found by series expansions (Abramowitz, 1972; Poole & Borchers, 1979). The pvalue associated with the chi-square probability distribution is defined in terms of series by the following expressions.

For odd number of degrees of freedom use:

$$p = 1 - \frac{(\chi^2)^{(v+1)/2} \bullet e^{(-\chi^2/2)} \bullet (2/(\chi^2 \bullet \pi))^{1/2} \bullet Z}{1 \bullet 3 \bullet 5 \ldots \bullet v}$$

and for even number of degrees of freedom use:

$$p = 1 - \frac{(\chi^2)^{(v/2)} \bullet e^{(-\chi^2/2)} \bullet Z}{2 \bullet 4 \bullet 6 \bullet \ldots v}$$

where $Z = 1 + \sum_{i=1}^{\infty} \frac{(\chi^2)^{(i)}}{(v+2) \bullet (v+4) \bullet (v+6) \bullet \ldots (v+2i)}$

In order to find a pvalue, first find the value of Z. A spreadsheet macro is displayed in Table 2 for calculating Z. For macro programming see O'Leary and O'Leary (1990). Macro programming is primarily the same in DOS or in Windows. Macros are small programs that can be used to automate specific calculations. Once the series Z is found, the rest of the pvalue calculations are easily performed. A test of hypothesis can also be implemented as part of a spreadsheet. Formulas for calculating the pvalue for a specific chi-square statistic and how the spreadsheet can be used to make decisions regarding whether to reject or not to reject the null hypothesis are shown in Table 3.

The macro in Table 2 is started by using commands TOOLS, MACRO, RUN at the top of the spreadsheet screen (cursor must be placed at start of macro). As the macro runs, the user must enter the value for the chi-square in cell C2 and the degrees of freedom in cell C3. A number of initial values are entered in cells C5, C7 and C9. The sum Z is then calculated until the difference between 2 successive results is less than 10^{-17} in absolute value. Using 10^{-17} provides the same accuracy as the LOTUS function @CHIDIST.

Insert Table 2 About Here

After Z and the pvalue are found, conditional expressions are implemented and statistical tests of hypothesis are performed. Table 3 demonstrates how to conduct a test of hypothesis. For an odd number of degrees of freedom the pvalue formula must include the square root of $1/(2\pi)$. The necessary value is placed in cell C6. In Table 3 formulas are displayed that calculate the pvalue, ask the user for the value of alpha (significance level) and compare the pvalue (observed significance level) with this alpha and output the decision to reject or fail to reject the null

hypothesis. If pvalue is less than or equal to alpha the null hypothesis is rejected. If the pvalue is greater than alpha, the null hypothesis is not rejected.

Insert Table 3 About Here

A spreadsheet that applies the formulas in Table 3 and calculates pvalues and conducts a test of hypothesis is shown in Table 5. Column A is used for counting iterations. In cell D2 is the chi-square value and in cell D3 is the number of degrees of freedom. The formula in cell C6 determines whether the number of degrees of freedom is odd or even and includes the $1/(2\pi)$ value if odd. Depending on whether v is odd or even, (v+1)/2 or v/2 is entered in cell D6. The term Z times the number in C6 times $\exp(-\chi^2/2)$ times $\chi^{2\wedge}$D6 is computed in cell C9. Column B provides the denominator for the pvalue. The percentile is computed in column C. Column D computes the pvalue when applicable. The decision to reject or accept the null hypothesis is made by comparing the value in cell F3 with the pvalue. Column F shows the user the degrees of freedom and makes comparisons for finding the pvalue. In order to reject or not reject the null hypothesis, the user must enter the value of alpha in cell F3. The COPY, PASTE commands can be used to copy these formulas down the spreadsheet for any desired number of degrees of freedom. The headings for the computations are displayed in Table 5.

Linking Multiple Worksheets

In LOTUS 1-2-3 for Windows, the use of multiple worksheets is possible. Instead of separate computations on the same sheet or separate files, worksheets can be linked. For example, on sheet A the chi-square is calculated and placed in cell C11 and the number of degrees of freedom is entered in cell C12. On sheet B, Z is calculated and placed in cell C12. The chi-square

statistic is linked from sheet A by using +A:C11 and entered in cell C2 and the degrees of freedom value is also linked from sheet A by using +A:C12 and entered in cell C3. On sheet C, the chi-square statistic is entered by using +B:C2 in cell D2 and the degrees of freedom value is entered by using +B:C3 in cell D3. These worksheets can be easily named by clicking on the index tab at the top of the screen and typing in a name for a specific worksheet. For example sheet B was named Zmacro and +B:C2 becomes +Zmacro:C2. If B is linked to sheet C, take out formulas in cells D6 and D7 in the Z macro. The changing of worksheets can also be automated. In Table 2, after the Z value was calculated this Z value is entered on the next worksheet C by using +Zmacro:C12 in cell B6.

A complete chi-square analysis including calculating chi-square statistics and pvalues and making decisions can be conducted. Table 4 and Table 5 show the output for Example 1, using the ideas described in Table 1, Table 2 and Table 3.

Example 1. One thousand numbers were generated using a random generator (using COPY, PASTE, and @RAND in LOTUS can accomplish this task). The null hypothesis is: There is no difference in the number of values in the ten intervals: 1-100, 101-200... 901-1000, that is, the expected number of values is 100 in each interval. The alternative hypothesis is: There is a difference in the number of values in each of the 10 intervals, that is, the expected number of values is not 100 in each interval.

Insert Table 4 About Here

Insert Table 5 About Here

Finding Pvalues by Simpson's Rule

Determining pvalues and making decisions regarding the null hypothesis can also be found by using Simpson's Rule (Larson, Hostetler, & Edwards, 1998). Simpson's Rule is an approximation technique for finding the value of integrals impossible to do exactly. For a continuous function f on [a,b], $\int f(x)dx$ is approximated by

$$\frac{h}{3}[f(a) + 4f(a+h) + 2f(a+2h) + 4f(a+3h)+...+4f(a+(n-1)h) + f(b)].$$

where h = (b-a)/n.

Table 6 illustrates the use of Simpson's Rule for determing the gamma function of the degrees of freedom divided by 2 that is $\Gamma(v/2)$. The macro starts with the commands in F4. First the spreadsheet is cleared and the gamma function of the degrees of freedom divided by 2 is found by Simpson's Rule. Table 7 displays how the pvalue is calculated by Simpson's Rule. In Table 8, the decision macro is demonstrated. This macro asks the user to input alpha. The macro compares the pvalue to the alpha and makes a decison to reject or fail to reject the null hypothesis.

Insert Table 6 About Here

Insert Table 7 About Here

Insert Table 8 About Here

The output from Table 6 for Example 1 for $\Gamma(9/2)$ is 11.63166. For the lower limit a value of 0 was used and an upper limit of 1000 (large value-infinity) was used. The number of even subintervals 4000 was used with 9 degrees of freedom. The output from Table 7 and Table 8 for

Example 1 provides a pvalue of 0.10943 with a decision to not reject the null hypothesis. In the pvalue macro, 0 was used for the lower limit and 14.38 (chi-square) was used for the upper limit. The number of even subintervals 4000 was used with 9 degrees of freedom.

The gamma function macro starts in cell F4. The pvalue macro starts in cell F27 and the decision macro starts in cell F52. For comparison, the LOTUS built-in function @GAMMA(9/2) provides a result 11.63173 and @CHIDIST(14.38,9) gives 0.109435 .

More Examples for Exploration

Using technology for applying the chi-square probability distribution to a variety of problems enables students to acquire a broader view of the value of this statistic. in relevant situations. in learning, and in doing research.

In Example 2, a goodness of fit application is considered.

Example 2. The probability of a boy being born is 0.5. Using the binomial probability distribution, in a family with three children, the probability of having 0, 1, 2, or 3 boys is 0.125, 0.375, 0.375, and 0.125 respectively. A sample of 100 families each with 3 children is provided in Table 9. Does this data fit the binomial probability model with p = .5? Test at the α = .05 level of significance.

Insert Table 9 About Here

Since p is greater than alpha, the null hypothesis is not rejected. Apparently, the data fit the binomial probability distribution.

In Example 3, A statistical test of independence of two categorical variables is described.

Example 3. A sample of 530 persons was asked: Are you fearful of mathematics? The collected data is displayed in Table 10. The null hypothesis is: Does the sex of an individual indicate a difference in attitude of fear for mathematics? Test at the significance level of 0.05.

Insert Table 10 About Here

Since the pvalue is less than or equal to 0.05, the null hypothesis is rejected. There is a significant difference between sexes in attitude of fear for mathematics.

Benefits of Technological Use for Student Learning

In a spreadsheet environment, a template is easily constructed and can be expanded and implemented for more than one example. The benefits of a spreadsheet lie in the capability for the learner to use this technology as an electronic pencil and interact with concepts and do mathematics. Once concepts are understood, any technology could be used as a tool for doing more mathematics. Using computer algebra systems, such as DERIVE, MATHEMATICA, or MAPLE make calculations automatic but concepts are less often illustrated. A black box exists where mathematics is automated and meanings to what is calculated are lost.

Students using technology learn many things. Calculations become automatic. Focus on interpretation and setting up tests of hypothesis increase in importance. A spreadsheet is easy to use and program. Interactivity increases. Many more tests of hypothesis can be performed in less time. Mathematics can be done in more than one way. Building complex mathematics formulas is easily accomplished. Insight and intuition are gained with technology use. Exploring ideas that are impossible without the use of technology are possible. Concepts are studied in more depth.

Conclusions

A number of ways to use a spreadsheet to calculate chi-square statistics and pvalues for chi-square tests of hypotheses, and to make decisions to reject or fail to reject the null hypothesis of no significant difference are described. More problems and exercises can be analyzed in more meaningful ways. Technology use becomes a tool for studying and doing statistics.

Exploring in depth concepts without being lost in numerous calculations is invaluable. Using technological tools such as spreadsheets forces students to think and contemplate the outcomes and the correctness or incorrectness of calculations and results. With the increasing sophistication of technology, thinking about results becomes necessary.

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Appendix

Some Other Ways to Find Pvalues

Finding pvalues can be accomplished in many other ways. They can be found by applying computer algebra systems, spreadsheet built-in functions, and programmable calculators.

The pvalue related to the chi-square statistic can be found by using a computer algebra system such as DERIVE for DOS. In DERIVE, press AUTHOR expression and enter:

$$\frac{1}{\Gamma(v/2)2^{(v/2)}} \int z^{(v/2-1)} e^{-z/2} dz.$$

Press CALCULUS, INTEGRATE and enter lower limits and upper limits. When the expression is authored, use the MANAGE, SUBSTITUTE commands and enter a value for v, the number of degrees of freedom. Press APPROXIMATE and obtain the percentile. One minus this value yields the pvalue. For Example 1, DERIVE provides the answer of 0.109432 for a chi-square of 14.38 with 9 degrees of freedom. The Windows version of DERIVE works similarly.

Using the spreadsheet built-in function @CHIDIST(chi-square,degrees of freedom) also provides the pvalue. The only disadvantage to learning is that no meaning as to how this value is calculated is described. If the student wishes to use statistics without knowing the mathematical foundations behind the calculations, the use of this function is beneficial. Applying the LOTUS 1-2-3 function for Example 1 gives @CHIDIST(14.28,9) = 0.109435.

The algorithms illustrated with the spreadsheet macros described above are easily adaptable to programmable calculators. Programmable calculators such as the TI 81, TI 82, and TI 92 can be programmed for finding pvalues, chi-square statistics, and making decisions to reject or fail to reject null hypotheses. The availability and portability of programmable calculators permit students to study results of statistical analysis in convenient and effective ways.

Table 1. Calculating the Chi-Square Statistic

	A	B	C	D	E	F
1	Observed	O	O	O	O	O
2	Values	O	O	O	O	O
3						
4	Expected	E	E	E	E	E
5	Values	E	E	E	E	E
6						
7	Calculating the Chi-Square Statistic					
8	Number of Groups		10			
9	(+b1-b4)^2/b4					(+f1-f4)^2/f4
10	(+b2-b5)^2/b5					(+f2-f5)^2/f5
11	Chi-Square =		@sum(+a9..f10)			
12	Degrees of Freedom =		+c8-1			

Note. O represents the entered observed values and E represents the entered expected values. Cell A9 is copied down and over to cell F10. Using the COPY command, the spreadsheet can calculate as many cells as needed. Formulas in cells can be identified with capital or small letters.

Table 2. Finding Z by Spreadsheet Macro.

	A	B	C	D
2	Enter the chi-square statistic			
3	Enter df			
6				{goto}c2~{?}~
7				{goto}c3~{?}~
8				{let c5,1}~{let c7,1}~{let c9,1}~
9				{let c6,+c2^c5}~
10				{let c7,c7*(+c3+2*c5)}~
11				{let c8,c9}~
12				{let c9,c9+(c6/c7)}~
13				{let c5,c5+1}~{?}~
14				{if @abs(c8-c9)<10^-17}{branch d17}~
15				{branch d9}~
17				{goto}c12~+c9~{quit}~

Note. A macro can be placed anywhere on a spreadsheet. Cell numbers in the macro may change. If macro is linked from sheet A (Table 1), in cell C2 enter +A:C11 and in cell C3 enter +A:C12. Take out statements in cell D6 and cell D7. Using the statement {goto}C:F3 after {goto}c12~+c9~ in cell D17 takes the cursor from the computed Z on sheet B (Table 2) to the cell where the alpha is entered on the next worksheet, sheet C (Table 3).

Table 3. Formulas for Pvalues and Statistical Tests of Hypothesis

D2	+Zmacro:c2
D3	+Zmacro:c3
F3	0.05
B6	+Zmacro:c12
C6	@if(@int(d3/2)=d3/2),1,@sqrt(2/d2*@pi))
D6	@if(@int(d3/2)=d3/2,d3/2,(d3+1)/2)
A9	1
A10	+a9+1
B9	@if(@int(d3/2)=d3/2,2*a9,2*a9-1)
B10	+b9*(@if(@int(d3/2)=d3/2,2*a10,2*a10-1)
C9	(b6*c6*@exp(-d2/2)*d2^d6)/b9
D9	@if(d3=f9,1-c9,@na)
E9	@if(d9 >f3,"Accept","Reject")
F9	@if(@int(d3/2)=d3/2,2*a9,2*a9-1)

Note. If a spreadsheet is linked from a previous sheet B (Table 2) named Zmacro, in cell D2 enter +Zmacro:C2, in cell D3 enter +Zmacro:C3 and in cell B6 enter +Zmacro:C12. These values are χ^2, v, and Z respectively. Any cell formulas using the notation $ symbol means whenever formulas are copied down a worksheet, this value is kept constant.

Table 4. The Chi-Square Test Statistic for Example 1.

	A	B	C	D	E	F
1	Observed	88	98	89	81	117
2	Values	103	114	97	96	117
3						
4	Expected	100	100	100	100	100
5	Values	100	100	100	100	100
6						
7						
8	Number of groups		10			
9	Chi-Square	1.440	0.040	1.210	3.610	2.890
10	Calculated	0.090	1.960	0.090	0.160	2.890
11	Chi-Square =		14.38			
12	degrees of freedom =		9			

Note. The Z Macro provides a Z value of 8.626199 for a chi-square statistic of 14.38 with 9 degrees of freedom.

Table 5. Calculating the Pvalue and Making Decisions

	A	B	C	D	E	F
2		Enter Chi-square		14.38		Enter alpha
3		Enter df		9		
4						
5		Z sum	v term	(v+1)/2 or v/2		
6		8.626199	0.210407	5		
7						
8	Counter	denominator for pvalues	pecentile	pvalue	decision	df
9	1	1	841.5835	NA	NA	1
10	2	3	280.5278	NA	NA	3
11	3	15	56.10557	NA	NA	5
12	4	105	8.015081	NA	NA	7
13	5	945	0.890565	0.109435	Accept	9
14	6	10395	0.08096	NA	NA	11
15	7	135135	0.006228	NA	NA	13
16	8	2027025	0.000415	NA	NA	15

Note. The result in cell D13 agrees with @CHIDIST(14.38,9) = 0.109435

Table 6. Gamma Function by Simpson's Rule

```
      F
4     /rea3..e15~
5     {goto}b3~Enter lower endpoint~
6     {goto}a3~{?}~
7     {goto}b5~Enter upper endpoint~
8     {goto}a5~{?}~
9     {goto}b7~Enter number (even) of subintervals~
10    {goto}a7~{?}~
11    {goto}b8~Enter the df v~
12    {goto}a8~{?}~
13    {let a9,(+a5-a3)/a7}~{goto}b9~Value for h~
14    {let a12,a3^(a8/2-1)*@exp(-a3)+a5^(a8/2-1)*@exp(-a5)}~
15    {summing}
16    {let a12,(a12+4*((a3+(a7-1)*a9)^(a8/2-1))*@exp(-1*(a3+(a7-1)*a9)))*a9/3}~
17    {goto}b12~is the result~{let a17,a12}~

19    summing
20    {goto}b11~Counting~{for a11,1,+a7-4,2,f21}~
21    {let a12,a12+4*((a3+a11*a9)^(a8/2-1))*@exp(-1*(a3+a11*a9))}~
22    {let a12,a12+2*((a3+(a11+1)*a9)^(a8/2-1))*@exp(-1*(a3+(a11+1)*a9))}~
23    {return}
```

Table 6. Gamma Function by Simpson's Rule ...continued...

Note. Line 14 calculates f(a)+f(b). The subroutine {summing} computes the intermediate values for the approximation of the gamma integral. For 1 degree of freedom, do not enter 0 for the lower limit. Enter a number close to 0 to avoid an error of dividing by 0.

Table 7. Pvalues by Simpson's Rule

```
      F
27    /rea25..e37~
28    {goto}b27~Enter lower endpoint~
29    {goto}a27~{?}~
30    {goto}b29~Enter upper endpoint~
31    {goto}a29~{?}~
32    {goto}b31~Enter number (even) of subintervals~
33    {goto}a31~{?}~
34    {goto}b32~Enter the df v~
35    {goto}a32~{?}~
36    {let a33,(+a29-a27)/a31}~{goto}b33~Value for h~
37    {let a36,a27^(a32/2-1)*@exp(-a36/2)+a29^(a32/2-1)*@exp(-a29/2)}~
38    {calculate}
39    {let a36,(a36+4*((a27+(a31-1)*a33)^(a32/2-1))*@exp(-.5*(a27+(a31-1)*a33)))*a33/3}~
40    {let a37,1-a36/(2^(a32/2)*a17)}~
41    {goto}b37~pvalue~
42
43
44    calculate
45    {goto}b34~Counting~{for a34,1,+a31-4,2,f46}~
46    {let a36,a36+4*((a27+a34*a33)^(a32/2-1))*@exp(-.5*(a27+a34*a33))}~
```

Table 7. Pvalues by Simpson's Rule...continued...

```
47      {let a36,a36+2*((a27+(a34+1)*a33)^(a32/2-1))*@exp(-.5*(a27+(a34+1)*a33))}~
48      {return}
```

Note. Line 37 calculates f(a)+f(b). The subroutine {calculate} computes the intermediate values for the approximation of the chi-square integral. For 1 degree of freedom, do not enter 0 for the lower limit. Enter a number close to 0 to avoid an error of dividing by 0

Table 8. Decision Making Macro

	F
52	{goto}b39~Enter alpha~
53	{goto}a39~{?}~
54	{if a37>a39}{goto}a40~fail to reject null hypothesis~{quit}
55	{goto}a40~reject null hypothesis~

Note. Table 6. Table 7. and Table 8 were used as one spreadsheet to test the hypothesis for Example 1.

Table 9. Male Births

male births	0	1	2	3
number of families	16	36	29	19
expected number	12.5	37.5	37.5	12.5

Note. Using Table 1, Table 2, and Table 3, the output is: $\chi^2 = 6.35$, degrees of freedom = 3 and $p = 0.09577$ for Example 2.

Table 10. Fear of Mathematics.

	Yes	No
males	74	191
females	173	92

Note. Using Table1, Table 2 and Table 3, the output is: $\chi^2 = 74.31$, degrees of freedom = 1 and p = 0 for Example 3.